

Silicon, ASICs, and Other Detectors

Eric Wulf

Naval Research Laboratory

Silicon for Compton

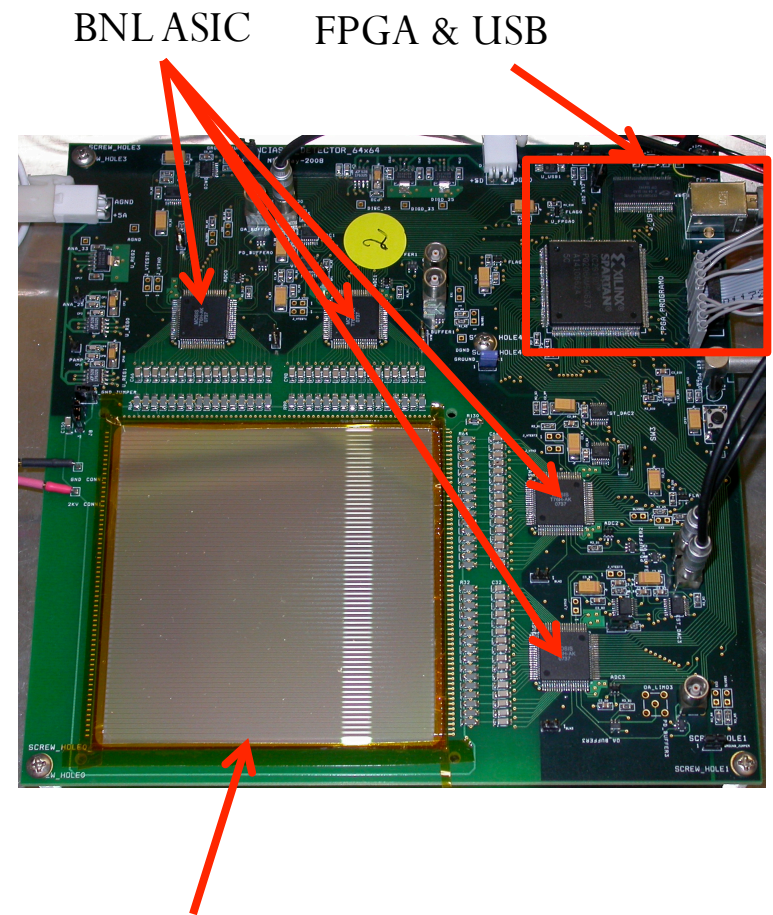
- Low-Z
 - Great Compton scatterer
 - Smallest Doppler broadening of materials under discussion
 - Need many layers to get interaction probability
- All Silicon instrument does not make sense
 - Too effective at scattering
 - Too many chances to interact in passive material
 - Full absorption unlikely
 - Need High-Z material for full absorption of incident gamma-ray while maintaining energy resolution
 - Ge, CZT, CdTe

Thin vs Thick Silicon

- Thin
 - Pros
 - Electron tracking
 - Position resolution
 - Cons
 - Number of electronics channels
 - Number of layers
- Thick
 - Pros
 - Fewer detectors and electronics
 - Increased interaction probability per layer
 - Cons
 - No electron tracking
 - Currently no depth resolution

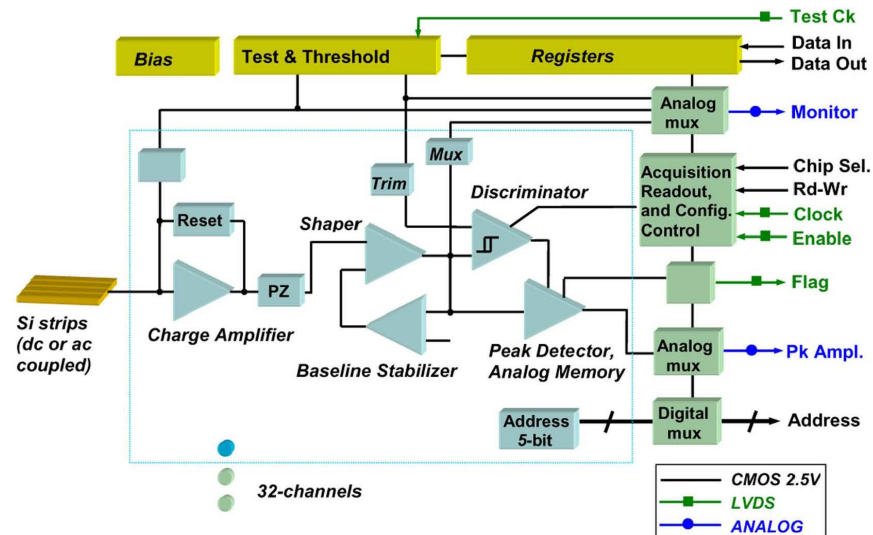
Current Thick Silicon Detectors

- 150 mm diameter wafers
 - 2 mm thick
 - Strip pitch of 1.41 mm
 - 64 strips
 - Depletion voltage of $\sim 700\text{V}$
 - Leakage current of 300-700 nA at room temperature
 - 270 nA in dry nitrogen
 - 4 nA/strip ignoring guard ring
 - $\sim 100\text{ nA}$ at 4°C



6" Detector

ASIC Design



Si Strip Detector ASIC

[De Geronimo, et al. 2008]

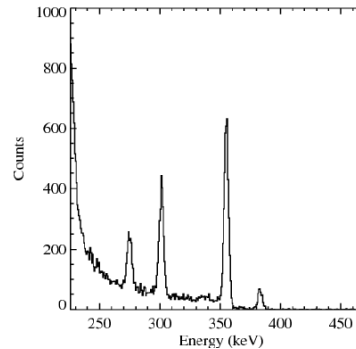
- 32 channels – pos/neg polarity
- 200 e⁻ RMS at 30 pF and 4 us peaking
- 400:1 dynamic range
- Peak Detect and memory
- Readout mux
- 5 mW per channel

- Front-end power, Detector Capacitance, Peaking Time and Noise/Resolution are related and influence ASIC design
- Threshold of the system is dependent on the resolution

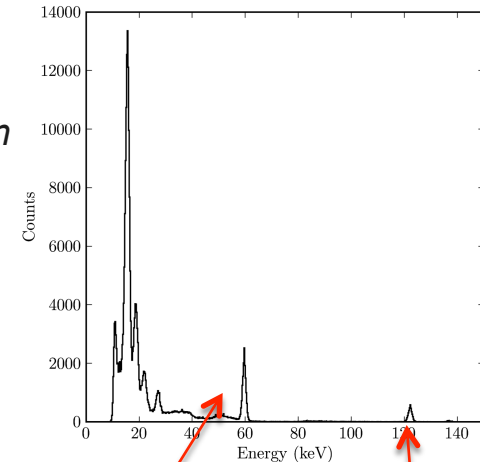
Timing Energy Threshold $\sim (\text{ENC})(\text{Peaking Time})/(\text{Timing Resolution})$
 25 keV threshold for 1 us peaking and 10 ns time resolution

ASIC Readout

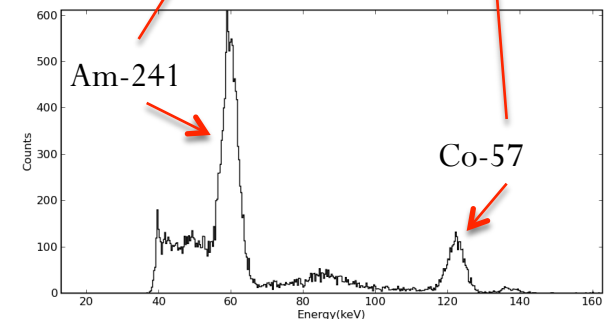
- Developed at BNL
 - 32 channels per ASIC
 - Polarity selection
 - Preamp, shaper, leading-edge discriminator, peak & hold, sparsification
 - 4 peaking times (0.5, 1, 2, 4 μ s)
 - 15 keV – 3.7 MeV energy range
 - Dual gain settings
 - 4 mW/channel – 166 mW/ASIC
 - 81.5 cm² x 0.2 cm with 4 ASICs
 - ~ 0.5 gm/cm²
 - 123 cm²/W or 57 g/W



*Spectrum of a ¹³³Ba source
with ~ 4 keV FWHM resolution*



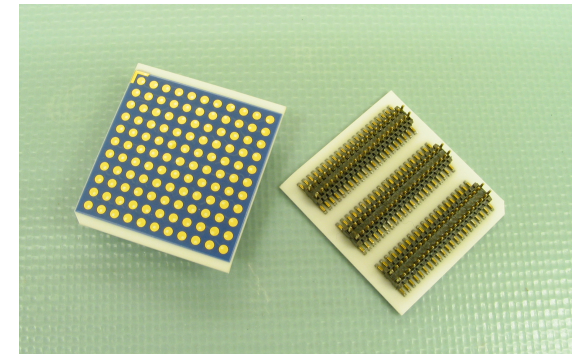
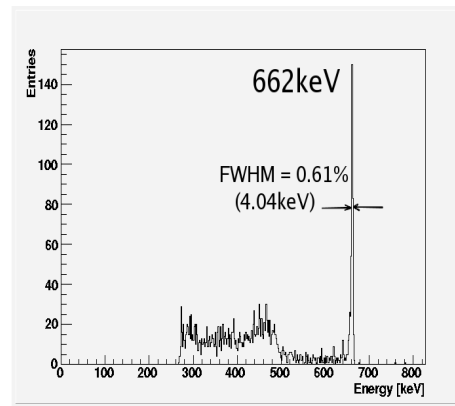
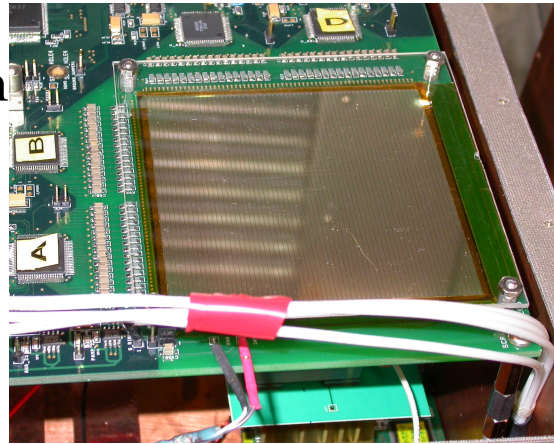
Small detector cooled to -40C with
1.4 keV FWHM at 59.5 keV



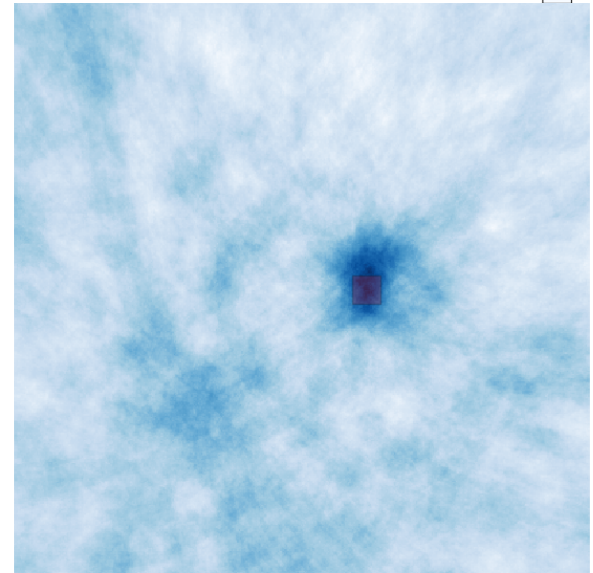
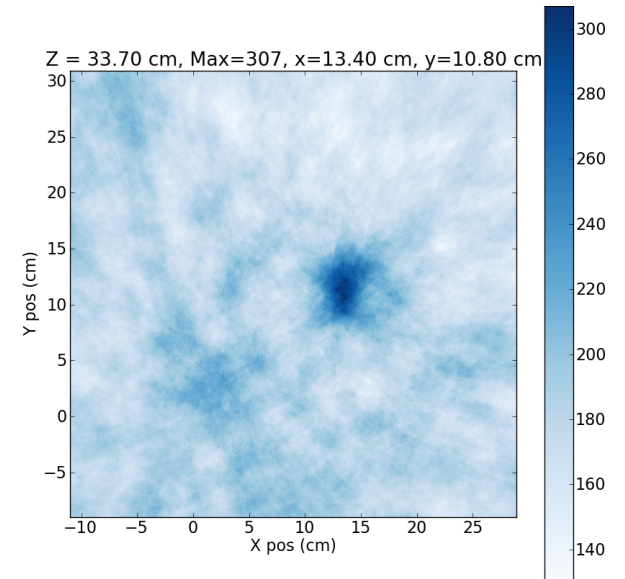
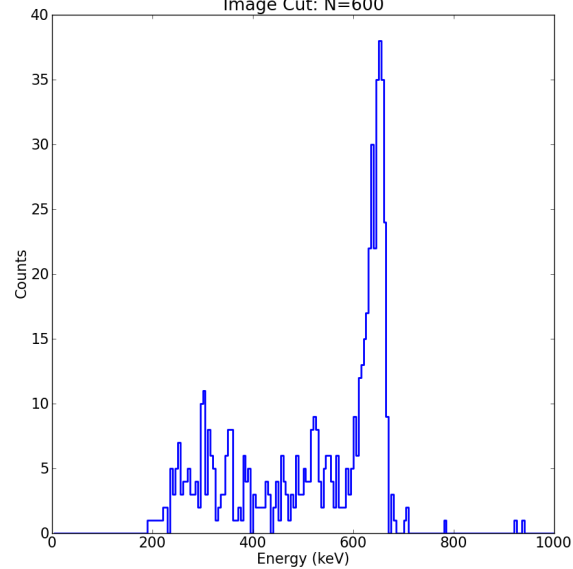
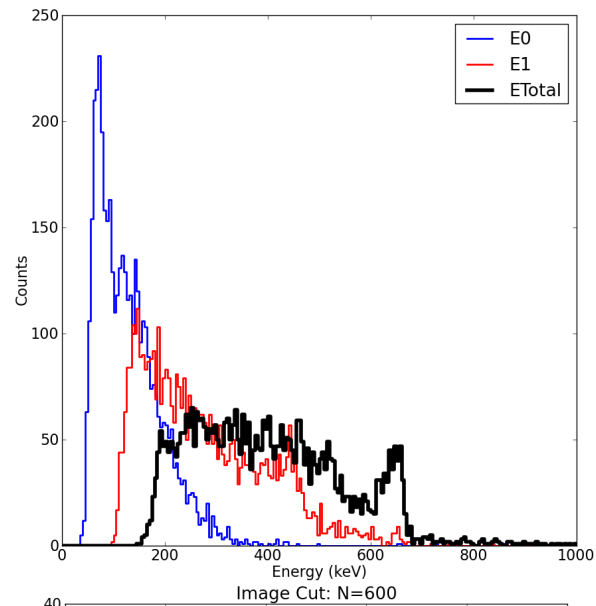
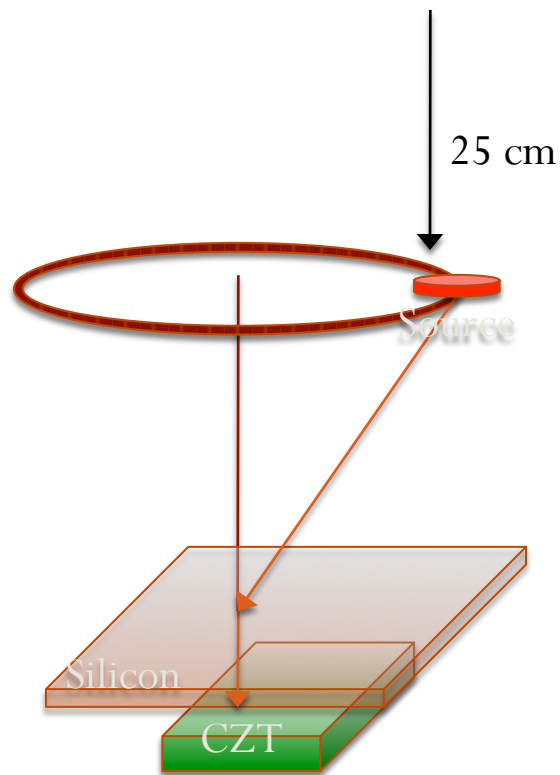
Full detector at room temperature
with 4.8 keV FWHM at 59.5 keV

Silicon & CZT Compton Telescope

- CZT detector available from collaboration with Washington University
- Pixelization
 - 0.25 mm
 - ASIC readout with BNL ASIC
- Silicon scatterer and CZT calorimeter
 - Integrated into one box
 - Logic levels connected
 - Coincident pulser data
 - Coincident gamma-ray data
 - Reconstructed data

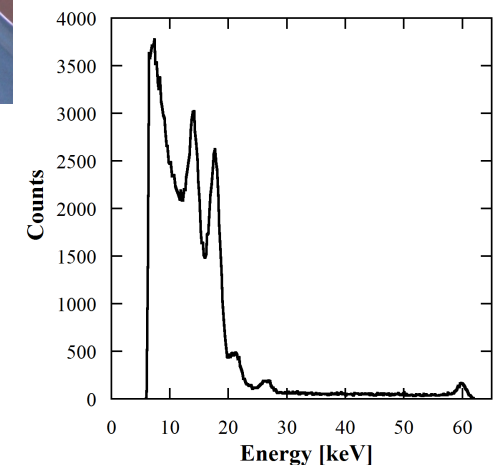
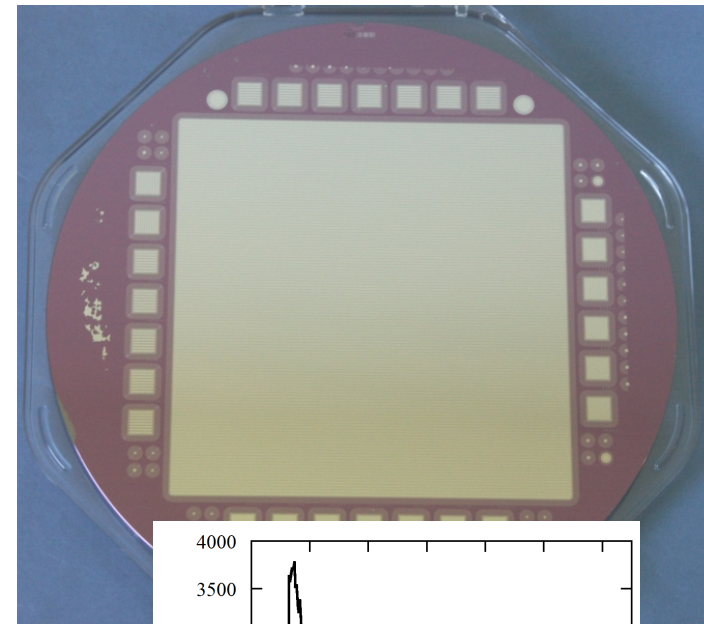


CZT Results



Large Area Detectors

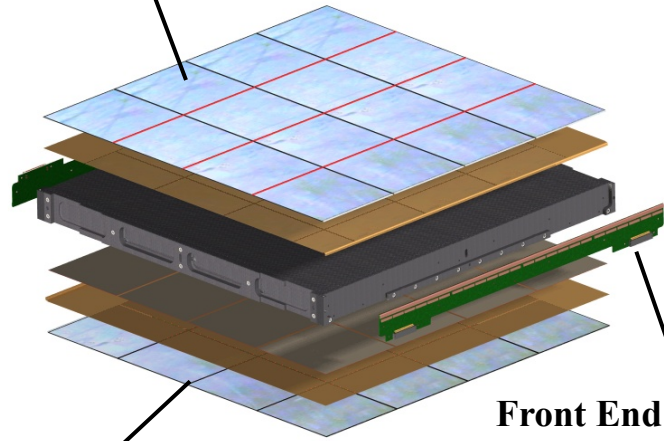
- Made at NRL
 - 200 mm diameter wafer
 - 675 μm thick
 - Thickest material currently available
 - 156 cm^2 active area
 - 128 strips
 - 920 μm wide and 124 mm long
 - Guard ring structure 2.3 mm wide
 - 9 $\text{k}\Omega\text{-cm}$
- Depletion at $\sim 60\text{ V}$
 - Leakage current of 100 nA
 - 6 keV FWHM at 59.5 keV
 - 10% usable strips
- Small detector at edge
 - 2.6 keV FWHM at 59.5 keV



Daisy Chaining Detectors

LAT Tracker Tray

4x4 array Single sided SSD



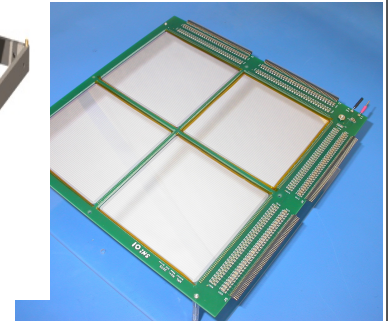
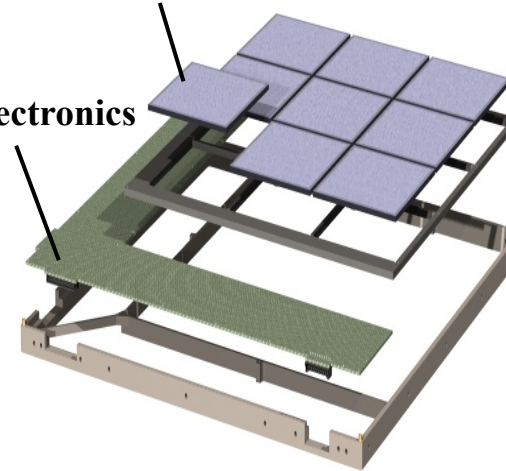
4x4 array Single sided SSD

- Silicon Compton requires double-sided strip detectors to position the Compton interactions in a single crystal
- Preferred detector thickness is 2 mm or greater
 - Higher depletion voltages
 - Higher quality silicon material

Silicon Compton Tray

3x3 array Double sided SSD

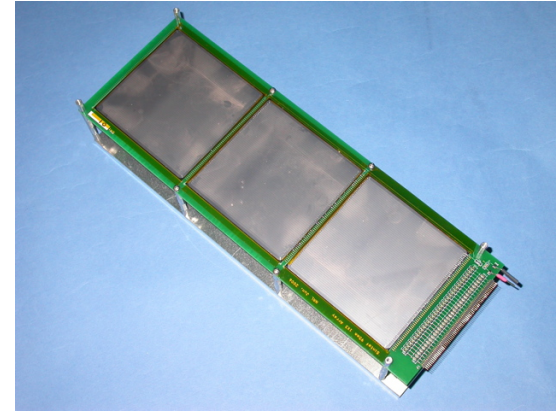
Front End Electronics



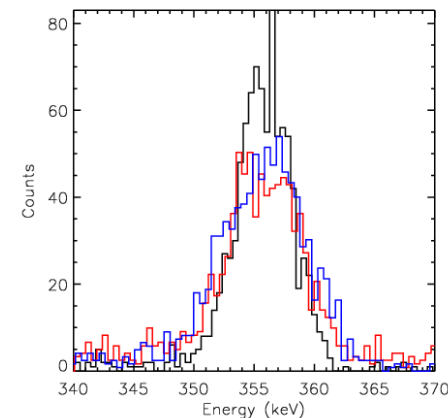
- Requires spectroscopy of events in silicon
 - more complex front ends
 - Pulse amplitude measurement
- Performance improves with lower energy threshold – better noise performance
- Fewer channels but likely higher power per channel

Tiling Detectors

- Reduce electronics needed
 - Move electronics to perimeter
 - Decreased passive mass
 - Connect detectors in ladder
- 3x3 array reduces number of ASICs from 36 to 12
 - Increased capacitance (~ 30 pF per strip)
- $368 \text{ cm}^2/\text{W}$ or 73.6 g/W
 - New version of the ASIC can further reduce power



3 9-cm detectors in series



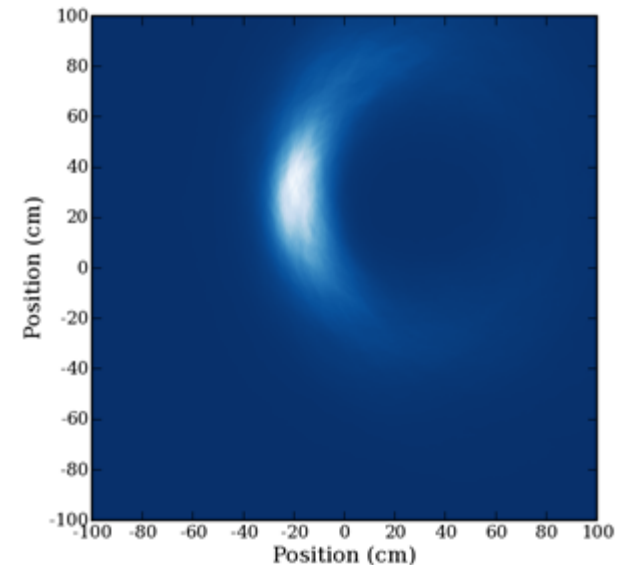
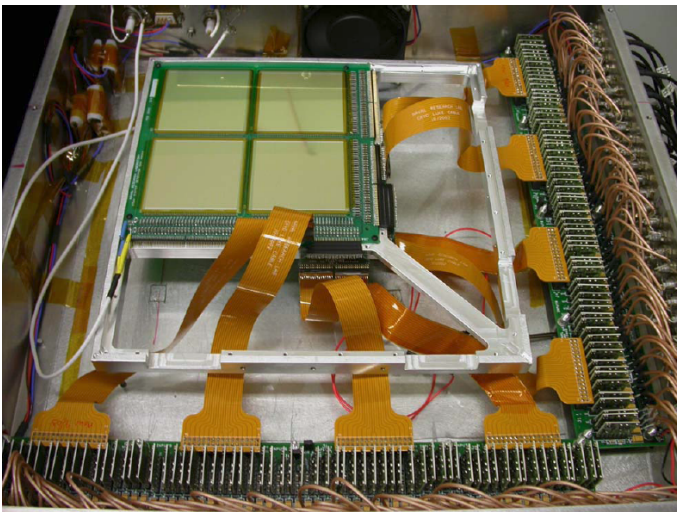
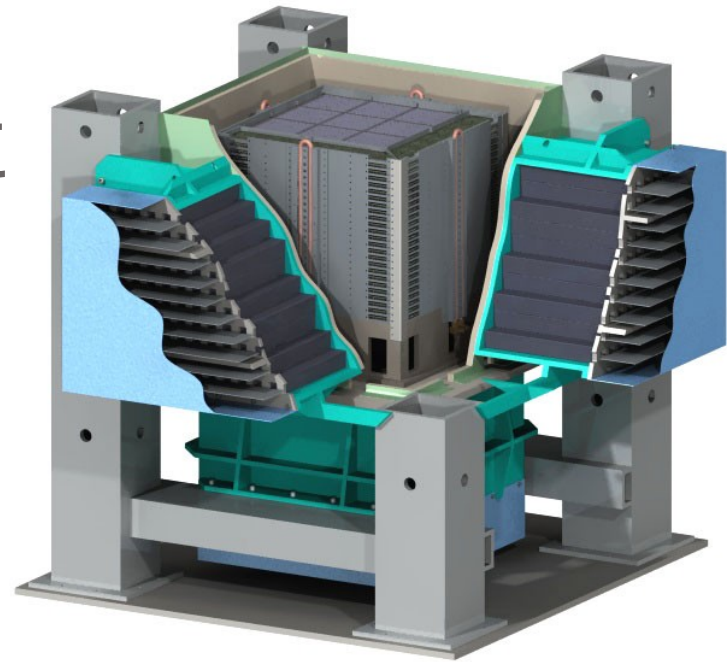
^{133}Ba line (356 keV) for 1 (black: 5.2 keV), 2 (red: 6.8 keV) and 3 (blue: 7.6 keV) detectors coupled together.

Future of Silicon

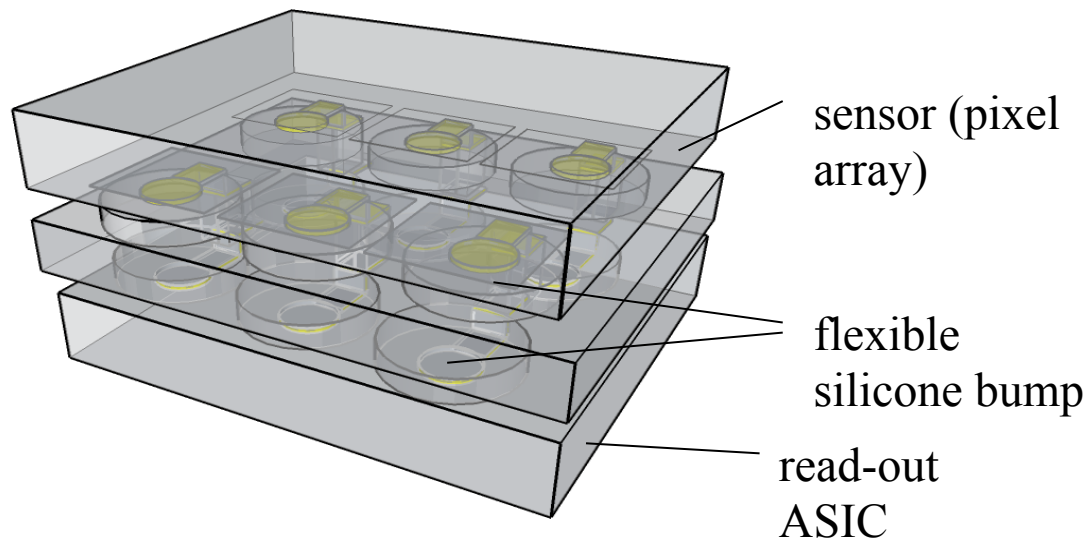
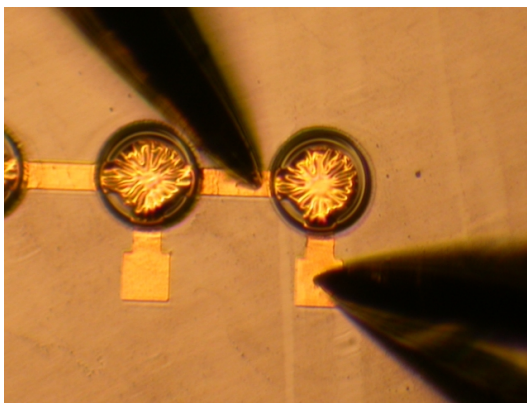
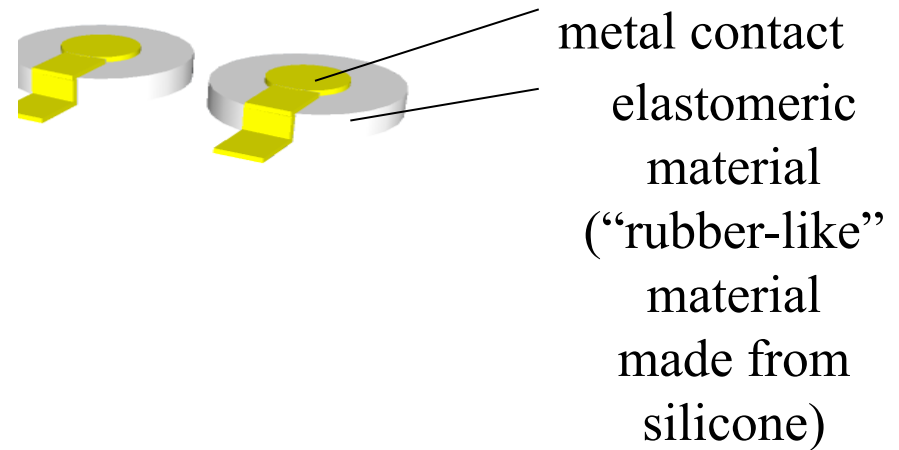
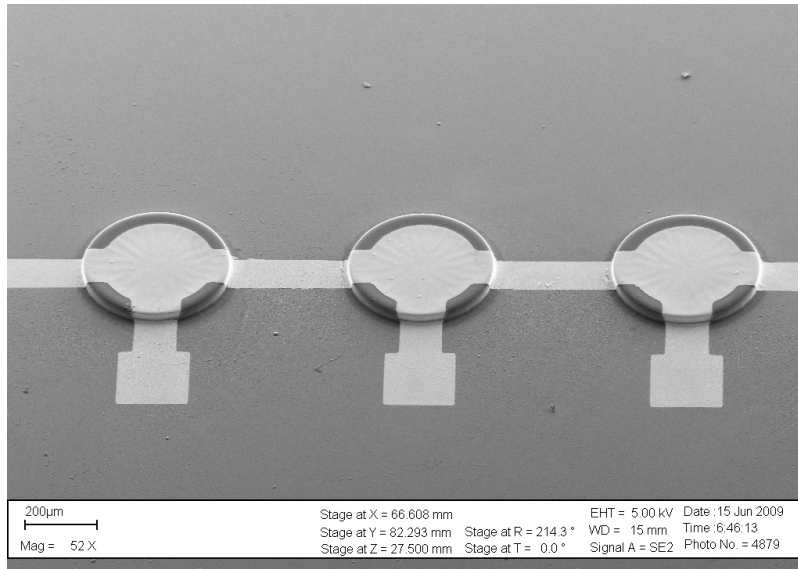
- Extensive research effort ongoing in Silicon
 - Many groups pursuing silicon detectors
 - For a Compton telescope
 - Improve energy resolution at room temperature
 - Increase area of the detectors
 - Increase thickness of the detectors
 - Improved ASICs with decreased power requirements
 - 3x3 array of 5 mm thick 6" detectors
 - $734 \text{ cm}^2 \times 0.5 \text{ cm}$ using 12 ASICs
 - 184 g/W

Prototype Concept

- 3x3 array of thick silicon detectors
- Surrounded by high-Z detectors (Ge, CZT, CdTe) to absorb scattered gamma-rays



CdTe Reusable Interconnects

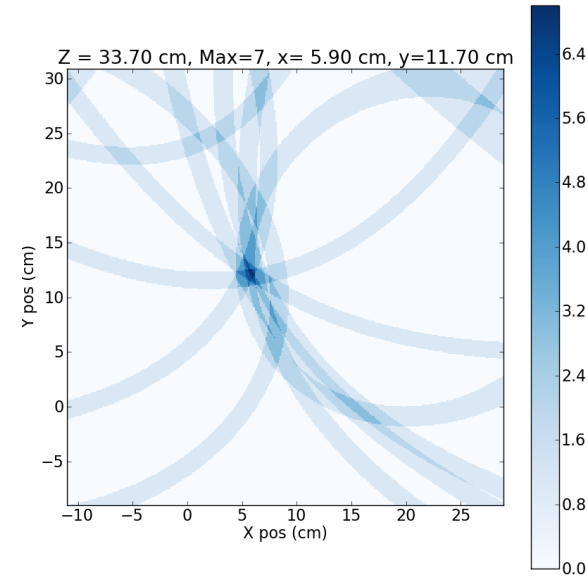
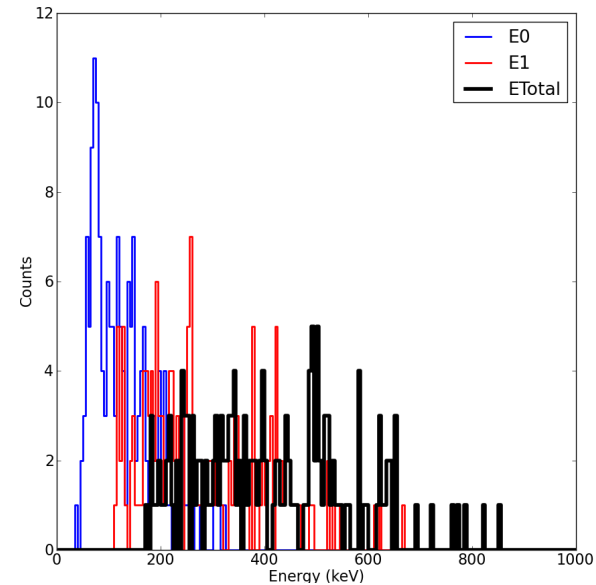


Current Semiconductor Detectors

Detector	Pros	Cons
Thick Silicon	Fewer electronics channels, Low-Doppler Broadening, good energy resolution	Suitable primarily as scatterer, Best resolution at $< 0^{\circ}\text{C}$, 0.5 – 1 cm thick is optimal
Thin Silicon	Electron tracking, Low-Doppler Broadening, good energy resolution	Suitable primarily as scatterer, Increased number of electronics channels, Small g/cm^2
CZT	Very large g/cm^2 , True room temperature operation	Individual detectors fairly small, Large Doppler-broadening when used as scatterer
CdTe	Large crystals, Readout properties similar to Silicon and Germanium	Currently only 1 mm thick, Large Doppler-broadening when used as scatterer
Germanium	Best energy resolution, Signal processing allows 3D tracking	Higher Doppler-broadening if used as scatterer, Cooling/Large power demands

Low Signal Sensing

- Reduce counts by a factor of 5
 - 164 events
 - No discernable Cs-137 peak
 - No discernable localization
 - Cut on the isotope energy
 - 12 events
 - Localization apparent
 - 7 (almost 8) go through correct position



Thick Silicon Goal

- Push for largest area detectors
 - Reduce passive mass
 - Reduce electronics count
- Push for thickest detectors
 - Reduce passive mass
 - Reduce electronics count
 - Increase interaction probability per layer
- Final Goal
 - 12" wafers with 5 mm thick silicon
 - 1.2 g/cm²
 - 156 cm² active area
 - Elements being approached by B. Philips and M. Christophersen